Method and Apparatus for Image Detail Enhancement without Zigzagged Edge Artifact

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Field of the Invention

The present invention relates to image detail enhancement, and in particular, to image detail enhancement to improve the sharpness of an image.

Background of the Invention

Image detail enhancement is frequently used in digital video systems such as digital television sets. A goal of image detail enhancement is to improve the image sharpness. As such, image high frequency components that contain image details are extracted, enhanced and added back to the original image so that the details in the processed image become more obvious to a viewer.

FIG. 1 shows a block diagram of a conventional image detail enhancement system 10, also known as unsharp masking. An original image f is passed through a low pass filter (LPF) 12 to obtain an image f_1 (unsharp signal), wherein the

image f_1 is subtracted from the original image f in a node 14, to obtain the difference $(f-f_1)$. The difference $(f-f_1)$ is then boosted by a factor of K $(K>0)$ in a multiplier 16, before being added back to the original image f in a node 18, to generate an enhanced output image g. The relationship between the output signal g and the input signal f can be expressed as:

$$g=(f-f_1)*K+f \qquad (1)$$

The low pass filter 12 can be either a one dimensional (1D) filter or a two dimensional (2D) filter. If it is a 1D filter, the detail enhancement process can be performed along the horizontal and vertical directions separately.

Generally, an image edge can be enhanced in detail enhancement processes because an image edge is usually associated with high frequency image components. However, using a system shown in FIG. 1, some artifacts can also be introduced into the edge area.

An instance of such visual artifacts is a zigzagged edge due to conventional image detail enhancement. An example of the zigzagged edge artifact is described in conjunction with

FIGS. 2A-B. FIG. 2A shows an original image edge 20, wherein each small square block 21 in the edge 20 represents one image pixel. The edge direction has a low angle relative to the horizontal direction. Along the horizontal direction across the edge, there is a long luminance transition range 22 from dark area to bright area or vice versa, as indicated in FIG. 2A. The luminance transition range 22 refers to the length of the luminance transitioning area of an edge either along the horizontal direction or along the vertical direction across the edge. With such a luminance transitioning area around the edge, the boundary of the edge shown in FIG. 2A looks generally smooth even though the edge has a limited image resolution.

A conventional image detail enhancement process is applied to the image edge 20 of FIG. 2A to generate the enhanced image 24 in FIG. 2B. Because in an image detail enhancement process high frequency components are boosted, the luminance transition range 22 may become shorter (or sharper). As can be seen in FIG. 2B, the luminance transition range 22 along the horizontal direction has become much shorter relative to that in FIG. 2A. As a consequence, the edge boundary now looks zigzagged. The more the image is enhanced in the detail enhancement process, the

more obvious this kind of artifact would be. As a result, even though the image in FIG. 2B is enhanced, the quality of the image looks poor due to the degradation of edge quality.

The problem shown in FIG. 2B exists for most slant image edges. A slant image edge refers to an image edge whose direction is not exactly vertical or horizontal. Only when an image edge has exactly vertical or horizontal direction or precisely $\pm 45^{\circ}$ (i.e., $+45^{\circ}$ or -45°) direction, it is immune to the problem shown in FIG. 2B. Otherwise, a slant image edge can develop zigzagged edge artifacts if it is enhanced substantially.

As such, there is a need for a method of preserving edge quality and preventing zigzagged edge artifacts in detail enhancement, without sacrificing the enhancement of other image details that are not prone to zigzagged edge artifacts when enhanced.

Brief Summary of the Invention

The present invention addresses the above needs. In one embodiment the present invention provides a method for detecting slant edge areas in an image comprising a plurality of pixels, and for preventing zigzagged edge

artifacts in an image detail enhancement process. Because zigzagged edge artifact can occur at slant image edge areas due to over-enhancement, the purpose of the slant edge detection is to locate the pixels of slant edges so that the enhancement gain at those pixel locations can be appropriately reduced or suppressed.

In one example slant edge detection process, pixels in a rectangular window of pixels centered with a selected/current pixel are used to detect a slant edge at the current pixel location. The center as well as the luminance transition range of a slant edge is detected.

Once a slant image edge is detected and its luminance transition range is determined, a corresponding gain suppression factor/parameter is calculated and assigned to each pixel within the detected luminance transition range of the slant edge. Using the suppression factor, in a detail enhancement process the enhancement gain for a slant edge pixel is selectively adjusted such that the original length of the luminance transition range is maintained and the zigzagged edge artifacts associated with the enhanced slant edge are reduced.

The adjustment of enhancement gain for pixels within the detected luminance transition range of a slant edge is based on several factors, including a pixel's position within the luminance transition range of a slant edge, the luminance contrast of the edge and the amplitude of the enhancement gain. In one example, these factors are utilized in determining a gain suppression factor that is combined with the enhancement gain (generating an adjusted enhancement gain) so that the enhancement for slant edge pixels is selectively reduced to avoid/reduce introduction of zigzagged edge artifacts during image detail enhancement.

Other objects, features and advantages of the present invention will be apparent from the following specification taken in conjunction with the following drawings.

Brief Description of the Drawings

FIG. 1 shows a block diagram of a conventional detail enhancement system;

FIG. 2A shows an example smooth-looking slant image edge before detail enhancement;

FIG. 2B shows the same edge in FIG. 2A after detail enhancement, wherein the edge becomes zigzagged due to over enhancement;

FIG. 3 shows an example functional block diagram of an embodiment of a detail enhancement system according to the present invention;

FIG. 4A shows a diagram of pixels inside an example window centered with a current/selected pixel and its neighboring pixels, for the detection of slant image edge at the current pixel location;

FIG. 4B shows an example of values for pixels in the window shown in FIG. 4A;

FIG. 4C shows an example binary pattern data corresponding to the pixel values in FIG. 4B, in which a slant edge can be detected, with a luminance transition range of 9 pixels wide;

FIG. 5A shows pixels in an example luminance transition range;

FIG. 5B shows an example function curve used in the system of FIG. 3 to calculate a gain suppression factor for a pixel based on the location of that pixel in the luminance transition range of a slant edge; and

FIG. 6 is a flow chart of an embodiment of steps used in the system of FIG. 3 for obtaining gain suppression factor for each pixel location in the luminance transition range of a slant edge according to the present invention.

Detailed Description of the Invention

Referring to the example functional block diagram in FIG. 3, in one embodiment the present invention provides a detail enhancement system 300 that detects slant edge areas in an image comprised of pixels, and prevents zigzagged edge artifacts in image detail enhancement.

The present invention addresses the above needs. In one embodiment the present invention provides a method for detecting slant edge areas in an image comprising a plurality of pixels, and for preventing zigzagged edge artifacts in an image detail enhancement process. Because zigzagged edge artifact can occur at slant image edge areas due to over-enhancement, the purpose of the slant edge detection is to locate the pixels of slant edges so that the enhancement gain at those pixel locations can be appropriately reduced or suppressed.

In one example slant edge detection process, pixels in a rectangular window of pixels centered with a selected/current pixel are used to detect a slant edge at the current pixel location. To do so, first the luminance mean value for the window pixels are determined, and then the value of each pixel inside the window is compared with the luminance mean value. Only the comparison results are

used in the succeeding detection process. To facilitate the processing, such comparison results can be saved as binary pattern data for each pixel in the window. Then, by checking the binary pattern data, it is determined if the current pixel is a center pixel in a luminance transition range of a slant edge. If it is, then the exact luminance transition range of the edge is detected based on the binary pattern data.

Once a slant image edge is detected and its luminance transition range is determined, a corresponding gain suppression factor/parameter is calculated and assigned to each pixel within the detected luminance transition range of the slant edge. Using the suppression factor, in a detail enhancement process the enhancement gain for a slant edge pixel is selectively adjusted such that the original length of the luminance transition range is maintained and the zigzagged edge artifacts associated with the enhanced slant edge are reduced.

The adjustment of enhancement gain for pixels within the detected luminance transition range of a slant edge is based on several factors, including a pixel's position within the luminance transition range of a slant edge, the luminance

contrast of the edge and the amplitude of the enhancement gain. In one example, these factors are utilized in determining a gain suppression factor that is combined with the enhancement gain (generating an adjusted enhancement gain) so that the enhancement for slant edge pixels is selectively reduced to avoid/reduce introduction of zigzagged edge artifacts during image detail enhancement.

The example system 300 in FIG. 3 includes a slant edge detector (SED) 310, a suppression factor generator (SFG) 320 and a low pass filter (LPF) 330. The SED 310 is used to detect the location and the length of a luminance transition range of a slant edge. Based on the slant edge detection result, as well as an enhancement gain parameter K and the local luminance contrast, the gain suppression factor $\alpha (0 \leq \alpha \leq 1)$ is generated by the SFG 320 for each pixel location within the detected luminance transition range. The suppression factor α is combined with the original enhancement gain parameter K and jointly determine the enhancement intensity at each pixel location.

The system 300 further includes the summation nodes 340, 360 and the multiplication node 350. The LPF 330, and the nodes 340, 350 and 360 in FIG. 3, operate in a similar

manner as the LPF 12, and the nodes 14, 16 and 18 in FIG. 1, respectively. In operation of the example system 300 of FIG. 3, the original image f is passed through a low pass filter (LPF) 330 to obtain an image f_1 (unsharp signal), wherein the image f_1 is subtracted from the original image f in the node 340, to obtain the difference $(f - f_1)$. The difference $(f - f_1)$ is then boosted by a factor of K $(K > 0)$ in the multiplier 350 based on a suppression factor α according to the present invention, before being added back to the original image f in the node 360, to generate an enhanced output image g. As such, the relationship between the output signal g and the input signal f in the system 300 can be expressed as:

$$g = (f - f_1) * K * \alpha + f \qquad (2)$$

Conceptually, for slant edge pixels where zigzagged edge artifact is likely to occur in detail enhancement, a relatively small α is generated. For pixels that do not belong to a slant edge, α takes a value of 1, which means that no gain suppression is needed at those pixel locations.

To determine the value of α at a selected pixel location, the SED 310 first detects whether the current

pixel belongs to a slant edge area. As such, the SED 310 detects all the slant edge pixels and provides the center location as well as the length of the luminance transition range of the slant edge.

An example method of slant edge detection is provided in co-pending patent application, entitled: "Method and Apparatus for Detecting the Location and Luminance Transition Rage of Slant Image Edges, pending patent application" by Xianglin Wang and Yeong-Taeg Kim, attorney Docket SAM2.0027, incorporated herein by reference. Referring to the example diagram in FIG. 4A, detection of slant image edges is conducted in a rectangular window 400 of pixels 410 centered with a current pixel 420. Further, FIG. 4B shows example values 430 for the pixels 410 in the window 400 of FIG. 4A. The mean value of a plurality of the pixels 410 inside the rectangular window 400 is calculated. Then, the value of each pixel inside the window 400 is compared with the mean value. Only the comparison results are used in the succeeding detection process. To facilitate the processing, such comparison result can be saved as a binary pattern data 450 such as shown in FIG. 4C for each pixel in the window 400. For example, if a pixel 410 in the rectangular window 400 has a value (e.g., luminance) that is

not smaller than the mean value, the corresponding binary pattern data for that pixel can be assigned a value of 1. Otherwise, the corresponding binary pattern data for that pixel is assigned a value of 0 (e.g., FIG. 4B and 4C).

The binary pattern data 450 corresponding to the pixels 410 within the rectangular window 400 are checked to determine if the current pixel is a center pixel in a luminance transition range of a slant edge. If it is, the length of the luminance transition range is determined by checking the binary pattern data. In the example shown in FIG. 4C, the binary pattern data 450 corresponding to the window 400 including the current pixel 420, indicate that the current pixel 420 is a center pixel in the luminance transition range of a slant edge. In addition, the length N of the luminance transition range can be determined as 9 pixels wide according to the method provided in co-pending patent application referenced above.

Once the SED 310 determines that the current pixel 420 is the center pixel in the luminance transition range of a slant edge and the length of the luminance transition range is detected as N pixels wide (wherein N is an odd number value, $N \leq W$), then enhancement of all the N pixels within

the luminance transition range needs to be appropriately suppressed using a suppression factor. Referring to the example row of pixels 500 in FIG. 5A, (i.e., Row 0 in FIG. 4A with pixels' row index omitted), the current pixel 420 is denoted as p_0 and shown as the hollow circle with a cross inside in FIG. 5A. Pixel p_0 is the center pixel in the luminance transition range of a slant edge. The other pixels 410 are shown as hollow circles. Pixel $p_{-\frac{N-1}{2}}$ is at the left end of the luminance transition range, and pixel $p_{\frac{N-1}{2}}$ is at the right end.

As noted, the basic idea for generating a suppression factor is that the enhancement at the center pixel location should be suppressed more than other pixels. As such, away from the center pixel within the luminance transition range, suppression becomes less and less. Outside the luminance transition range, enhancement is not affected by the slant edge detection at the current pixel location.

Accordingly, an example method of generating a gain suppression factor uses a suppression function such as used by the example curve 550 in FIG. 5B. The curve 550 indicates the gain suppression factor assigned based on the

pixel location inside the luminance transition range N as shown in FIG. 5A. A value $s, (0 \leq s \leq 1)$, is assigned as the gain suppression factor for the center pixel p_0, wherein away from the center pixel p_0, the gain suppression factor increases in an essentially linear fashion from s up to 1. In a general form, for a pixel p_i, $(-\frac{N-1}{2} \leq i \leq \frac{N-1}{2})$, in FIG. 5A, a gain suppression factor can be determined as:

$$\alpha_c = |i| * (1-s) * 2/(N+1) + s \qquad (3)$$

Here, α_c is a candidate/temporary gain suppression factor for the enhancement at pixel p_i. The candidate gain suppression factor α_c may or may not be the final gain suppression factor α for that pixel location. This is because the luminance transition ranges detected at different pixel locations may overlap with one another and, therefore, it is possible for a pixel to reside in an area with overlapped luminance transition ranges of slant edge. As a result, multiple candidate gain suppression factors would be available for the same pixel, in which case the smallest candidate gain suppression factor α_c should be selected as the final gain suppression factor α for that pixel location.

According to relation (3) above, when s is fixed, the value of the gain suppression factor depends on the ratio of $|i|*2/(N+1)$, indicating the relative location of a given pixel p_i within the detected luminance transition range of the slant edge. The center/current pixel p_0 has a gain suppression factor of s, and the pixels $p_{-\frac{N+1}{2}}$ and $p_{\frac{N+1}{2}}$ are just outside the luminance transition range detected at the current pixel p_0 location. The enhancement at these two pixel locations is not affected by the slant edge detection at the current pixel p_0. For other pixel locations shown in FIG. 5A that are within the luminance transition range, the gain suppression factor calculated from relation (3) is in the range of $[s, 1]$.

In addition to a pixel's location in the luminance transition range, the pixel's local luminance contrast is taken into consideration in determining the corresponding gain suppression factor. Here, the parameter s is related to the luminance contrast of the slant edge where the pixel is located. If the luminance contrast is high across a slant edge, it is more likely that zigzagged edge artifacts will occur when the edge is detail enhanced. Therefore, more suppression should be provided in that case with s taking a

smaller value. As such, in the example herein, the luminance contrast is determined within the detected luminance transition range of a slant edge according to the relation:

$$d = |I_{-\frac{N-1}{2}} - I_{\frac{N-1}{2}}| \qquad (4)$$

wherein $I_{-\frac{N-1}{2}}$ and $I_{\frac{N-1}{2}}$ represent the luminance value of pixel $p_{-\frac{N-1}{2}}$ and $p_{\frac{N-1}{2}}$ respectively in FIG. 5A. The value of d represents the absolute luminance difference between the pixels at the left end and the right end of the luminance transition range (e.g., pixels $p_{-\frac{N-1}{2}}$ and $p_{\frac{N-1}{2}}$, respectively). If the value of d is large, it means that the luminance contrast within the luminance transition range is high.

Once the value of d is calculated, the parameter s can be determined as:

$$s = 1 - \max(0,\ \min(1,\ (d - T_1)/(T_2 - T_1))) \qquad (5)$$

wherein T_1 and T_2 are two predetermined threshold values, $T_2 > T_1 \geq 0$. According to relation (5), when the value of d is smaller than T_1, then s would have a value of 1. In this

case, no suppression is provided. When the value of d is larger than T_2, then s would have a value of 0, which means that the enhancement at the corresponding pixel location is fully suppressed (i.e. no enhancement). When the value of d falls between T_1 and T_2, then s would have a value between 0 and 1.

Generally, according to relation (5), if the value d is large, then s would have a relatively small value, which means that more suppression is provided to the enhancement of the pixels within the detected luminance transition range. Otherwise, if the value d is small, it means that the luminance contrast within the luminance transition range is low. In that case, it is less likely for zigzagged edge artifacts to occur in detail enhancement, and as such, less suppression is provided according to relations (3), (4) and (5).

In relation (5), the values of T_1 and T_2 need to be adjusted when the enhancement gain value K is changed. As shown in FIG. 3, K is used to control the overall intensity of detail enhancement. When K has a large value, the image is enhanced at a higher degree. In this case, even if the

luminance contrast across a slant edge is low, the enhanced edge can have zigzagged edge artifacts if the value of K is large enough. Therefore, to effectively prevent zigzagged edge artifacts in detail enhancement, K must also be taken into consideration. In the example herein, the value of K is used in determining the values of T_1 and T_2 for relation (5). The relations between K and the threshold values T_1 and T_2 are:

$$T_1 = C_1 / K \quad (6)$$

$$T_2 = C_2 / K \quad (7)$$

wherein, C_1 and C_2 are constants, which can be determined by feeding various test images into the system 300 and checking the enhancement results under different values of K. The criterion is that the enhanced images should not have noticeable zigzagged edge artifacts. Once the values of C_1 and C_2 are determined in the testing process, they are fixed when the system 300 is used in application.

Based on relations (3) through (7), the gain suppression factor α is related to: (i) the location of a pixel in a luminance transition range of a slant edge, (ii) the luminance contrast in the luminance transition range, and

(iii) the value of enhancement gain K.

As noted above, the candidate gain suppression factor α_c in relation (3) may or may not be the final gain suppression factor for that pixel location. This is because the luminance transition ranges detected at different pixel locations may overlap with one another and, therefore, it is possible for a pixel to reside in an area with overlapped luminance transition ranges of slant edge. As a result, multiple candidate gain suppression factors would be available for the same pixel, in which case the smallest α_c should be selected as the final gain suppression factor α for that pixel location.

In order to do so, the SFG 320 (FIG. 3) utilizes a temporary buffer for storing the intermediate suppression factor for each pixel location. Initially, all the data in the temporary buffer can be set to 1. Then, the data may be updated based on newly generated candidate suppression factors. In the buffer, the suppression factor for a given pixel location is denoted as α $(0 \leq \alpha \leq 1)$). When a new candidate suppression factor α_c is generated for this pixel location according to relation (3), the original data α can

be updated as:

$$\alpha = \min(\alpha, \alpha_c) \qquad (8)$$

whereby, the smaller of α and α_c is selected and stored in the temporary buffer as the updated suppression factor for that pixel location. When a suppression factor at a given pixel location is no longer to be updated by the processing at the remaining pixel locations, it is considered as the final suppression factor used for the enhancement at that pixel location.

FIG. 6 shows an example flowchart of an embodiment of the steps of a process for obtaining a gain suppression factor α for each pixel location according to the present invention. The process includes the step of: Detecting if the center pixel p_0 is a center pixel in a luminance transition range of a slant edge (step 600); If it is, then determining the length of the luminance transition range of the slant edge (step 610); Then determining the luminance contrast according to relation (4) above (step 620); Calculating parameter s, according to the relation (5) above (step 630); Calculating a new candidate suppression factor for each pixel within the luminance transition range according to relation (3) above (step 640); and Updating

the suppression factor according to relation (8) above (step 650). When there is a next pixel to process, the process moves to that pixel location and repeats the above processing steps (step 660).

Using the above method and system for obtaining gain suppression factors, the detail enhancement around slant image edges can be effectively suppressed so that the slant edge is enhanced appropriately essentially without introduction of zigzagged edge artifacts therein.

While this invention is susceptible of embodiments in many different forms, there are shown in the drawings and will herein be described in detail, preferred embodiments of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspects of the invention to the embodiments illustrated. The aforementioned detail enhancement system 300 according to the present invention can be implemented in many ways, such as program instructions for execution by a processor, as logic circuits, as ASIC, as firmware, etc., as is known to those skilled in the art. Therefore, the present invention is not limited to the example embodiments

described herein.

The present invention has been described in considerable detail with reference to certain preferred versions thereof; however, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.